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PARTIAL AMNESIA FOR A NARRATIVE FOLLOWING APPLICATION OF THETA FREQUENCY ELECTROMAGNETIC FIELDS?

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ABSTRACT

Twenty-four university students were instructed to listen to a three-minute narrative whose propositional and syntactic structure had been standardized. During either the first, second, or third minute of the narrative, subjects (n = 6/group) were exposed to a 5-Hz electromagnetic field (Relaxit) that was applied to either the left or right side of the head at the level of the temporal lobe. Subjects then retold the story within 5 minutes. Discourse analysis of each subject's transcript was completed by an expert who was not familiar with the condition of the subjects. There was a significant field condition effect that accounted for 40% of the variance in verbal measures. Subjects that had been exposed to the 5-Hz field during the first minute of the narrative displayed less than half the number of references to the narrative compared to the control group. There was a significant type of reference (recall vs inference) by field condition interaction. The field applied during the first minute reduced the number of inferences substantially more than the number of direct recalls relative to these values for the control group. These results suggest that the application of ELF fields near the temporal lobe during the electrically labile stage of consolidation for a complex verbal behavior may have affected the memory for this material.

INTRODUCTION

Most experiments concerning the effects of ELF (extremely low frequency) electromagnetic fields upon human behavior have emphasized simple, redundant,

and repetitive tasks. Such procedures do allow greater ease and control in the measurement of possible ELF-related effects. However, they lack the sensitivity that may be required to detect weak effects or alterations that are only evident when the applied field interacts with ongoing cognitive processes. They would include memory consolidation or coding and would be more representative of everyday behavior than the relatively contrived tasks of the usual test environment.

A recent study by Michaud and Persinger (1) indicated that 5-Hz but not 20-Hz magnetic fields (near the side of the head) influenced the memory of a complex cognitive task. In that study, subjects were instructed to listen to a 3-minute narrative called "The Dinosaur Egg Hunt"; its propositional structure, segmentation, and method of analysis have been developed by Frederickson (2). While listening to the story, the subjects were exposed to either 5-Hz, 20-Hz, or no field (sham) conditions during either the first, second or third minute of the narrative. Whereas the number of direct recalls were not influenced by the field treatments, the subjects who had received the 5-Hz field during the first minute of the narrative displayed twice as many inferences (than direct recalls) for the material that had been presented during that minute compared to the other treatments.

We suspected that ELF magnetic fields influence complex behaviors, specifically those that are occurring at the time of field application. Clinical conditions (unpublished data) that facilitate imagery may enhance the interaction between the ongoing cognitive processes and the applied fields, particularly when they are focused around the temporal lobe and are within theta frequency (4-8 Hz). The speculation was further supported by anecdotal cases where extraordinary alterations in verbal style were displayed by subjects who were suspected of displaying endogenous, contained alterations in the temporal lobe due to drug-induced or idiopathic, focal epilepsy (3).

Neuroelectrical support for the possible effects of weak, externally applied ELF fields upon language processing (consolidation) can be inferred

from the work of Ojemann (4). He reported several forms of transient dysphasia, such as anomia, during simultaneous presentation of a verbal stimulus with direct electrical stimulation of the temporal lobe. The stimulations interfered with an ongoing language task. Optimal currents (that did not produce after discharges) and frequencies disrupted the consolidation process when they were localized in one of many possible microlocations (about 5 mm^2 areas) within the so-called silent regions of the temporal cortex.

The temporal lobe, particularly its deep structures (the amygdala and hippocampus) are one of the most likely foci through which applied weak ELF electromagnetic fields could influence cognitive processes. This region is electrically labile (as indicated by kindling phenomena) and of course is intimately involved with language. Moreover, if the hypothesis of Geschwind (5) and the work of Goldensohn (6) can be generalized, there may be active cortical columns (about 250 microns in diameter) in all human brains. They would be potential sources of subclinical electrical microseizures (no blatant motor correlates) that might be stimulated by appropriate ELF fields and consequently alter ongoing cognitive processes.

Although multisentence verbal behavior is a routine behavior, its analyses can be difficult. To investigate the cognitive processes associated with comprehension and learning, researchers have developed techniques for representing the semantic content of sequences of a discourse as well as procedures for scoring and coding the information that subjects might recall from the discourse. By comparing the text of a recalled protocol against the propositional content of the actual text, the researcher can infer the cognitive operations that were (or were not) utilized in the comprehension. For the most part, these processes are highly interrelated with the means by which they are measured, namely memory.

One procedure has been developed by Fredericksen (2); it allows verbal material, such as a narrative, to be evaluated according to basic propositions or syntactic structure. Essentially, they are compositional, ideational, and

grammatical units of the narrative. Further divisions are made into the elements within the propositions and their relationship within the proposition and to other propositions. When a subject's protocol or transcript of what he remembers about a narrative (to which he has listened) is analyzed, it is first divided into frames. Frames are schema by which the listener has organized the material.

The material within the frames can be compared with the original propositions in the story and further evaluated with respect to the nature of the reference. Two basic references, as applied by Musgrave (7), have been used: direct recalls and inferences. Direct recall of the phrase "Jill jumped over a crack in the sidewalk" would be the sentence verbatim. An inference would be something like "Jill skipped over a hole in the pavement." These references are easily differentiated and counted.

We decided to replicate the Michaud and Persinger study by using only the effective (5-Hz) treatments. Because the transcripts were not analyzed under blind conditions in that study, this option was incorporated into the present design. In addition, we decided to use third-year students as subjects since they usually have more sophisticated and consistent verbal capacity than first-year university students who were used in the first study.

METHOD

Subjects

A total of 24 third-year university students served as subjects; they were enrolled in a third-year psychology (evening) course and obtained 2% bonus marks for participation. The age ranged from 20 to 45 years of age. Twenty of the subjects were female and 4 were male. All subjects were right-handed.

Procedure

Each subject was tested singly and alone in an acoustic chamber (8). Each subject wore a modified, plastic motorcycle helmet to which a Relaxit was attached. (The Relaxit is a commercially available EM device that is manufactured by Electro Medica Office, Rexdale, Ontario, M9V 2G2.) For half the numbers of subjects, the Relaxit was attached (by a rubber band) on the left side of the helmet; for the other half, it was attached on the right side. One of two Relaxits was used: 5-Hz or sham.

The 5-Hz Relaxit generated a magnetic field from an internal solenoid; the rise time of the pulse was 50 microseconds with an asymmetric plateau duration of 500 microseconds. According to the manufacturer, the field is about 10 gauss at a distance of 5 cm from the solenoid source and 1 gauss at 10 cm. The sham Relaxit was the same size, shape and color as the 5-Hz source except that the internal battery had been disconnected from the field solenoid. Care was taken to insure that the field source of the 5-Hz Relaxit was attached to the helmet surface that was just over and above the ear (mid-temporal lobe). This would give a calculated distance of about 5 cm from the outside of the helmet to the surface of the cortex (inside the skull).

After the experimenter had left the chamber and closed the door, the experiment began. Each subject had been told to listen for instructions. The same tape (1), that was recorded by a professional radio announcer, was played for each subject. The subjects were told they were going to hear a story and that they would be asked to tell the story in their own words upon its completion. The story was a 3-minute narrative called "The Dinosaur Egg Hunt;" its syntactic structure and segmentation had been completed by Frederickson (2,9).

There were four experimental treatments (groups). The first three received the 5-Hz field condition; Group 1 received the field for one minute during the first minute of the narrative; Group 2 received it for one minute

during the second minute of the narrative and Group 3 received it during the third minute of the narrative. The fourth group, the reference or control group, was not exposed to any field but did have a sham Relaxit attached to the helmet. The 5-Hz and the sham field devices were turned on and off from outside of the chamber; their operation was verified by the presence or absence of signals on an external monitor. At the end of the story, the narrator asked the subjects to retell the story in their own words; each version was taped. The experimenter did not talk to the subjects from the time he left the chamber until the subject had finished retelling the story. All subjects were tested during a six-week period between 1800 hr to 1900 hr or 2100 to 2200 hrs. Assignment to field conditions and to left or right hemisphere conditions was completed so that each condition was distributed over the entire test period.

Each subject's transcript of the taped version of the narrative was analyzed by an expert who did not know the experimental condition of the subjects. The first step was to determine the number of frames for each transcript. A frame is a general conceptual (usually a phrase) semantic strategy by which the listener coded or comprehended a proposition. The number of total frames per transcript were counted. Because they were highly correlated (r and rho = 0.92) with, and did not differ substantially from, the number of typed lines of the transcript, the numbers of frames were used as the measure of total verbal material about the narrative.

Once the transcript was segmented, each frame was designated on a separate working sheet that contained the discourse analyses of the narrative. On this sheet, each word of the narrative was designated according to grammatical, compositional, and syntactic features. Components of each frame were evaluated according to the type of reference to the actual components of the story. The two references were recall and inference. A recall was a verbatim sequence of words while an inference was a paraphrased reference to a component in the original text.

The total number of recalls and of references from portions of the story that were presented during the first, second, or third minute of the narrative were determined separately. Consequently, the data involved the numbers of recalls or inferences from minute 1, minute 2, and minute 3. In addition, an overall measure, the total number of frames (effectively lines) for each transcript was also counted.

The primary data were analyzed by four-way analyses of variance with two factors repeated. The two main effects were condition (5-Hz: minute 1; 5-Hz: minute 2; 5-Hz: minute 3; and control) and hemisphere or side (left vs right) of application. The two repeated measures were the three minutes of the narrative and whether the reference was a recall or an inference, within each minute. The analyses were completed by BMD P2V software on a DEC2020 System computer. Extra analyses were completed by SPSS software. They included a two-way analysis for the total number of frames per transcript as a function of field and hemisphere conditions.

RESULTS

A two-way analysis of variance for the total numbers of frames (segments) per subject demonstrated a significant ($F = 4.93$, $df = 3,16$, $p = .01$) field effect. The means and standard deviations for the numbers of frames per group are shown in Table 1. A posteriori analyses (Duncan's set at $p < .05$) indicated that the largest difference was between the group that had received the field during the first minute of the narrative and the control group. There was also no overlap in the numbers of frames for the group that received the field during the first minute (3 to 12) and the reference group (17 to 32).

Subjects who received the field at the level of the left temporal lobe displayed fewer frames than those who received the fields on the right side (see Table 1), although the effect was not statistically significant

TABLE 1

Means and standard deviations for the total numbers of references and total numbers of frames (lines) for subjects who received the 5-Hz field during the first, second, or third minute while listening to the narrative and for subjects who served as controls. Means and standard deviations for these measures for subjects who received the treatment on the left or right side of the head are also shown.

	REFERENCES	TOTAL SEGMENTS
FIELD CONDITION	TOTAL REFERENCES	TOTAL FRAMES
Minute 1	18.6 ± 13.7[a]	9.3 ± 3.5[a]
Minute 2	53.0 ± 36.3[b]	19.2 ± 10.5
Minute 3	31.8 ± 17.1	14.8 ± 6.6
Controls	73.5 ± 28.0[b]	24.5 ± 6.2[b]
HEMISPHERE		
Left	35.7 ± 25.5	14.4 ± 7.2
Right	52.8 ± 36.2	19.5 ± 8.0

a vs b = $p < .05$

($F = 3.11$, $df = 1,16$, $p < .10$). The interaction between field condition and hemisphere was not significant ($F = 0.45$, $df = 3,16$, $p > .05$). The field treatments accounted for 42% of the variance (eta = 0.65) while the hemispheric differences accounted for 9% of the variance (eta = 0.30); together the two main effects accounted for 51% of the variance in the numbers of frames.

The four-way analyses of variance (with two levels repeated) indicated a statistically significant difference between field conditions ($F = 5.26$, $df = 3,16$, $p = .01$) but no significant differences between hemispheres ($F = 2.63$, $df = 1,16$, $p > .05$) or a hemisphere by field interaction ($F < 1.0$) for the total numbers of references (recalls + inferences) in the narrative.

The means and standard deviations for these values are shown in Table 1. Duncan's a posteriori tests also indicated that the group that had received the 5-Hz field during the first minute of the narrative showed the greatest (least number of references) differences with the control group. There was also no overlap in the scores for the 5-Hz first minute group (4 to 39) and the control group (47 to 115).

As noted previously (1), there were significantly ($p < .001$) more inferences than recalls ($F = 146.68$, $df = 1,16$) for all subjects combined. In addition, there was a highly significant ($F = 10.50$, $df = 3,16$, $p < .001$) type of reference (recall vs inference) by field treatment interaction. The interaction is shown in Figure 1. The major source of this interaction was due to the greater reduction in the numbers of inferences relative to recalls for the group that received the field during the first minute of the narrative compared to the control group. This was clearly evident from one-way analyses on the recalls and inferences separately. Whereas the differences between the four treatments for recalls was marginally significant ($F = 3.03$, $df = 3,20$, $p = .05$), the differences were much larger ($F = 6.86$, $df = 3,20$, $p = .002$) for the numbers of inferences.

There were no other statistically significant interactions involving the minute of treatment presentation, by condition, type of reference, or hemisphere interactions. In addition, there was no significant correlation between the length of the transcript and the order of testing ($r = -0.21$). A posteriori analyses indicated that there was no significant difference between the male and female subjects.

DISCUSSION

The present study indicated that the application of 5-Hz electromagnetic fields near the temporal lobe during the presentation of a complex narrative significantly alters the subjects' references to the narrative. Like the

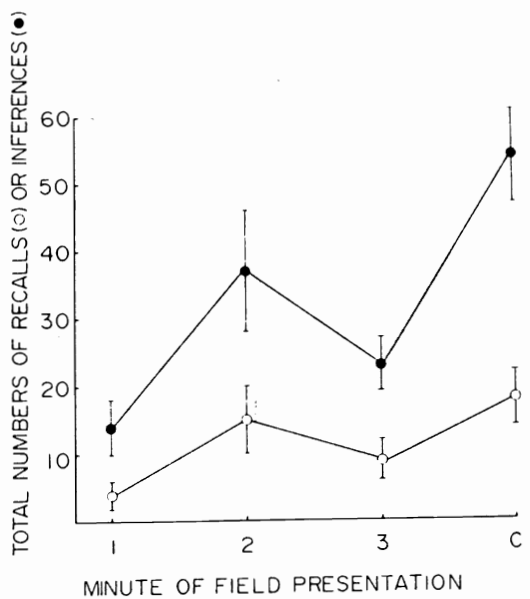

FIGURE 1

Total numbers of direct recalls (open circles) or inferences (closed circles) to the narrative for groups that were exposed for one minute to a 5-Hz electromagnetic field during the first, second or third minute of the narrative. The fields were generated from a Relaxit device and were presented at the side of the head near the temporal lobe. The control (C) group or sham-field group were exposed to a dummy Relaxit. Vertical bars indicate ± 1 standard errors of the mean.

Michaud and Persinger study (1), the greatest effect occurred in those subjects who received the 5-Hz field during the first minute of the narrative presentation. However, unlike the first study, the subjects who received the field during the first minute of the narrative showed a substantial decrease in both the number of frames (or index of total memory for the narrative) and the number of inferences.

One interpretation of this decrement is that the 5-Hz fields, when applied during the first minute of the narrative, interfered with memory consolidation. Consequently, when the subjects were instructed to recall the

information, they displayed fewer references (inferences or recalls) to the story. This occurred despite the statement before the story began that they would be instructed to retell the story when it was completed.

We suggest that the application of the field did not interfere with comprehension of the narrative for two reasons. First, the subjects who were exposed to the 5-Hz field during the first minute only of the narrative showed deficits for the material from the second and third minutes (when there was no field presented). This indicates that the 1-minute application of the field also influenced the consolidation of information that came afterwards. Secondly, the subjects that received the 5-Hz field for the first time during the last (third) minute also showed deficits for information that was presented before the field. It should be emphasized that the sensitivity of newly acquired information to very intense electrical currents (some types of electroconvulsive shock) is in the order of 10 minutes.

To insure that the general memory pattern was normal, we completed one-way analyses of variance on the total number of references (recalls + inferences) for each of the three minutes. The largest group differences ($F = 9.06$, $df = 3,20$, $p < .001$) occurred in the information that was recalled from the second minute of the narrative. Primacy and recency (the tendency to recall more of the first and last portions of a task) were evident for all groups. Consequently, the field effect was primarily to enhance the normal deficit in material recalled from the middle of the task (in this case, information from minute 2) even further.

The Michaud and Persinger study (1) did not show any statistically significant differences between field and control groups for the total numbers of frames per transcript. This had been expected in light of the hypothesis that weak theta-frequency electromagnetic fields (applied near the temporal lobe) should alter the type of memory rather than the amount of memory. Alterations in the amount of memory, particularly a decrease in memory

(partial amnesia), would be expected only in situations where the current induction began to interfere with ongoing neuroelectrical activity.

It is unlikely that control group peculiarities accounted for the differences in the results between the two experiments. We recalculated the mean numbers of segments for the two control groups of the Michaud study; they were 22.0 and 21.3 as compared to the mean of 24.5 in our study. Considering the 5% difference in interrater designation of segments (e.g., for a transcript of 20 segments, another rater may have a 19 or a 21), there appears to be no real difference between the control groups between studies.

Several slight differences in the procedures of the two studies may help account for the discrepancy. First, most of the subjects in the first study were tested in the afternoon while all of the subjects in the present study were tested in the evening. Secondly, these subjects were all third-year students compared to first-year students in the first study. Perhaps some unspecified aspects of motivation and attention are important prerequisites for this kind of field effect. Alternatively, since most of the present subjects were older than those from the first study, an age factor may be important as well.

Another possibility is the spatial position of the Relaxit. In this study, care was taken to be sure that the strongest portion of the field emission from the Relaxit was at the level of the temporal lobe just above the ear. In the previous study, the device was placed more caudally. At this time, it is difficult to conceive that a distance of 10 cm could be responsible for such a large discrepancy between the two studies. If this slight distance was the critical factor, then the results would indicate that the most intense (closest) field interferes with total narrative recall while weaker fields (further away from the temporal lobe, such as the Michaud study) affect the number of inferences but do not change the amount of memory.

We had hypothesized that ELF electromagnetic fields could directly stimulate the electrically labile cortical columns that should be present in

all cortices. When the numbers of columns within an area achieve a critical density, their existence may be recorded on the scalp surface by conventional electroencephalographic techniques (6). This would be seen as an electrical focus, such as with focal or temporal lobe epilepsy. We assume that the normal cortex shows labile cortical columns that are more statistically scattered over the cortical surface. They do not remain localized (as in the case of focal epilepsy) but change in accordance with the processes of memory consolidation (10). The applied ELF fields might influence these columns.

Of course, there are other possibilities; the effects noted in this study could reflect non-specific changes. It should be recalled that Mantle and Persinger (8) reported that 5-Hz fields evoked more subjective experiences of relaxation than 9-Hz treatments. The Relaxits in the Mantle study were applied at the level of the solar plexus. In an unpublished study, DeSano (11) found that a focused, 4-Hz field (sine wave; 0.5 gauss applied near the temporal lobe) evoked a significant decrease in heart rate (compared to baseline levels) after 10 minutes of exposure; neither a 1-Hz nor a no-field condition was associated with a significant change in resting heart rate. The subjects in the 4-Hz group also reported more references to sensations "of floating" than subjects from the other two groups.

Consequently, if the Relaxit, 5-Hz fields evoked "relaxation" or altered attention, then the decrease in references to the narrative that we found in this study may be due to problems of vigilance rather than direct effects on memory consolidation. However, we suspect that some amount of processing was affected since the subjects who received the Relaxits on the left hemisphere had less verbal output than those who received the same field applied to the right hemisphere. Although in this study, the hemispheric effects were not statistically significant ($p < 0.10$), unpublished studies indicate marginally significant ($p < .05$) hemispheric effects for unilingual right-handed people. This pattern may not be evident for fluently bilingual subjects.

In conclusion, two separate studies have indicated that the application of 5-Hz, pulse-like electromagnetic fields at the level of the temporal lobe can affect the recall of narrative material when the field is applied during the first minute of the narrative presentation. Although the direction and intensity of the results differed in the two studies, they indicate the potential sensitivity of alterations in the memory of complex narratives as indices of ELF electromagnetic field effects.

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